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Monitoring populations of Red-footed Boobies *Sula sula* and frigatebirds *Fregata* spp. breeding on Aldabra Atoll, Indian Ocean

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Frigatebirds and boobies have experienced considerable persecution and disturbance in the western Indian Ocean over the past century, and during this time populations of both groups declined or disappeared on many islands (Feare 1978, Carboneras 1992, Orta 1992, Cheke 2001). Some colonies are now protected but the size and population trends are poorly known for most Indian Ocean colonies. We report counts of frigatebirds and boobies made on Aldabra Atoll in March–May 2000, and compare them with previous counts to assess population trends. We also make recommendations for future monitoring, and comment on the use of small boats as a censusing platform for seabirds nesting in mangroves.

Aldabra Atoll supports the largest breeding population of frigatebirds in the Indian Ocean, and the second largest in the world, with c. 6,000 pairs of Lesser Frigatebird *Fregata ariel* and 4,000 pairs of Great Frigatebird *F. minor* (Reville 1983). The only other breeding site in Seychelles is nearby Cosmoledo Atoll which supports 200–400 pairs of each species (Rocamora & Skerrett 2001). Despite their global

importance the Aldabra frigatebird colonies have been censused only twice, in 1967 (Diamond 1971, 1975) and in 1976-1977 (Reville 1980, 1983).

Aldabra also supports a large breeding population of Red-footed Boobies *Sula sula*, estimated at 6,000-7,000 breeding pairs (Diamond 1971, 1974). Within Seychelles and the western Indian Ocean this is exceeded only by the Cosmoledo population (10,000-12,000 pairs; Rocamora & Skerrett 2001). The Aldabra population has been censused only once, in 1967-1968 (Diamond 1974). This is the only booby species known to nest on Aldabra.

Methods

Between 12-20 March 2000 AEB visited Aldabra and censused all the known frigatebird colonies and most of the Red-footed Booby colonies, covering more than half of the lagoon shoreline of the atoll in a 4 m long ocean kayak (K-light fold-up, Feathercraft Ltd., Vancouver, Canada). The kayak permitted access to most of the small channels among the mangroves and between small islets. Between 20 March and 9 May 2000 MB surveyed the remaining lagoon shore using a small motor boat, and R. Wanless counted boobies around Île aux Cedres. We generally remained 8-10 m away from the edge of the mangroves and shore, except where forced to pass through narrower channels, and plotted our locations on 1:25,000 orthophoto-maps as we moved along the shore. A hand-held tally counter was used to count frigatebird nests and, where common, booby nests. Binoculars were used to check and count a few nests which could not be approached within *c.* 30 m because of shallow water.

Red-footed Boobies were in two stages of breeding, which were counted separately. Most nests contained an adult apparently incubating. We checked *c.* 20 nests and all contained eggs, but some other birds might have been brooding small chicks. Colonies also contained large nestlings or newly fledged juveniles from an earlier nesting stage (hereafter called fledglings) sitting in or near nests. These were separated from older second-year immature birds by appearance: the fledglings had duller, more uniform brown plumage, sometimes with traces of down, paler and duller pink feet and legs, and black bills (Diamond 1974). A few large downy chicks were present in March and included in the fledgling count.

To include booby nests deep in the canopy, where adults on and off nests could not be distinguished from the boat, Diamond (1974) multiplied the total number of adults seen by an "incubating index", which was the ratio of adults seen on nests (incubating or brooding) divided by those definitely not on a nest. We chose not to apply this correction for several reasons. Adults were often roosting in areas where there were no nests. The ratio would need to be re-calculated for each section of colony to account for spatial and temporal variations in the attendance of off-duty adults. We encountered relatively few situations where we could not determine whether an adult was on a nest or not, although this sometimes required minor shifts of the boat position and the use of binoculars. Consequently, we made no effort to estimate the nests which might have been associated with the small numbers of adult boobies

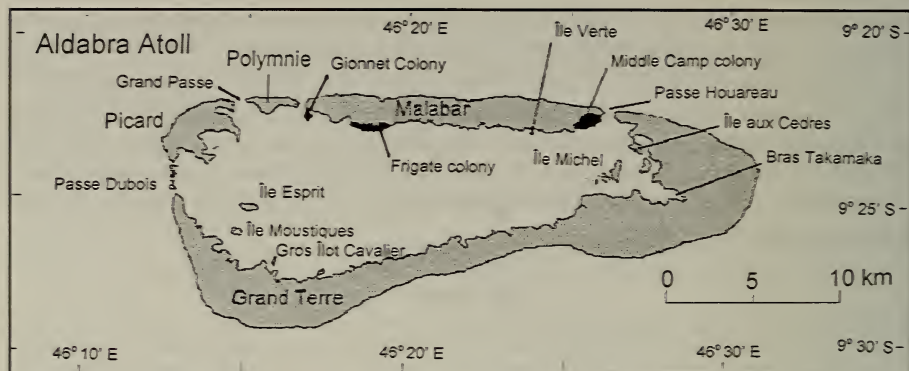


Figure 1. Map of Aldabra Atoll, showing islands and other features mentioned in the text, and the locations of the three frigatebird colonies (black areas).

seen deep in the canopy. The numbers given are our actual counts of visibly occupied nests. From the boats we could usually see deep into the canopy and our subjective impression was that we missed fewer than 10% of the booby nests, except for the colonies in and near Bras Takamaka. Booby nests along the mangrove fringe in Bras Takamaka and around Île aux Aigrettes were counted using binoculars from the opposite shore, 0.8-1.2 km away, and were probably under-estimated. We were unable to visit all the small channels in the mangroves of Bras Takamaka (Figure 1), where Diamond (1974) had reported several hundred booby nests, but MB and experienced rangers collectively estimated that there were c. 100 nests there, based on their experience during several explorations over the past two years.

At the time of the census both species of frigatebirds had large chicks. On Aldabra, fledglings of the two species can be distinguished using head colour (white or creamy in Great, and reddish in Lesser; Diamond 1975), but this takes experience (Reville 1983:69) and was not attempted. Counts of both species were pooled. About 1-2% of the nests contained an adult bird, which might have been shading a smaller chick (or less likely an egg) or in an empty nest. These were included in the total count. Reville (1983) estimated that boat counts recorded 80-90% of the frigatebird nests present, based on comparisons with counts from blinds inside colonies.

Results and discussion

Red-footed Booby

This species shows plumage polymorphism in the Indian Ocean (Le Corre 1999, Cheke 2001), but we saw only white morph adults, and no white-tailed brown morphs. Boobies nested in small clusters of nests scattered along the mangrove fringe of the lagoon, with a few nests also in *Pemphis acidula* shrubs and other trees. Nearly all nests were on the lee shores of islands or inlets, sheltered from the SE wind (the

strongest winds). We counted 4,095 nests with a sitting adult and 838 fledglings (Table 1). Most of these (71% of the nests with adults and 54% of the fledglings) were in areas not used for nesting by frigatebirds. Those boobies which did nest within the frigatebird colonies usually chose trees or bushes with no frigatebird nests, but this was not quantified. The majority of boobies therefore nested apart from frigatebirds, although frigatebirds often roosted nearby.

It is difficult to compare our counts with Diamond's (1974) census in 1967-1968 because his counts were made at a different time of year (between October and February), and the scale of Diamond's map makes it difficult to determine the boundaries of his count areas. The type of boat used for the counts (dinghy in Diamond's study, kayak in ours) should not affect the counts. Diamond counted the "Main Colony",

TABLE 1.

Distribution and numbers of Red-footed Booby nests in March-May 2000, compared with data from Diamond's (1974) census made between Oct 1967 and Feb 1968.

Island	Location	This study		1967-1968 (Diamond 1974)			Date of Diamond's survey
		Adults on nests	Fledglings and juveniles	Adults on nests	Calculated no. of nests	Fledglings and juveniles	
Picard	Lagoon and Grand Passe	28	7	11	12	2**	25 Nov
Malabar	Gionnet frigate bird colony	10	20	0	0	42**	11-12 Oct
Malabar	Gionnet to Camp Frigate colony	114	9	-	-	-	-
Malabar	Camp Frigate frigatebird colony	628	164	159	187	2	31 Jan
Malabar	Camp Frigate to Île Verte	1,022	110	90	125	10	15 Feb
Malabar	Île Verte to Middle Camp colony***	965	156	1,912	2,412	613**	12 Feb
Malabar	Middle Camp frigate bird colony***	534	200				
Grand Terre (west end)	Passe Houareau, Île aux Cèdres and un-named island	569	172	81	157	9	8 Nov & 4 Jan
Grand Terre (southwest end)	Île aux Aigrettes and outer Bras Takamaka	125*	- *	-	-	-	-
Grand Terre (southwest end)	Bras Takamaka inner channels	100*	- *	11	52	240**	13-14 Feb
Grand Terre (east end)	Gros Îlot Cavalier	0	0	13	13	1	8 Dec
Total		4,095	838		2,277	2,958	919
Within frigatebird colonies		1,172	384		2,071	2,599	615
Outside frigatebird colonies		2,923	454		206	359	304
Malabar Island totals		3,273	659		2,161	2,724	667

* Rough estimate of adults on nests, no estimate of fledglings

** Diamond's count for these areas included all immatures, not just fledglings and juveniles

*** Diamond's "Main Colony" covers these two areas

between Middle Camp and Île Verte, and the Bras Takamaka colonies twice, in October-November and again in February. He counted all other areas once, most in February. Considering only the February counts, which were closer to the months of our counts, Diamond's total for Aldabra was 2,277 adults on nests which he estimated represented 2,958 nests, including those not visible in the canopy (Table 1). Our count of nests with adults in 2000 was thus 80% higher than the 1967-1968 count, if we apply no correction for invisible nests to either data set. Comparing only Malabar Island, which contains the bulk of the boobies and was well covered by both censuses, the count of 3,273 nests with adults in 2000 was 51% higher than in 1967-1968 (Table 1).

Diamond's (1974) February 1968 estimate for "Main Colony" (1,912 adults on nests with no correction for invisible nests) was higher than the 1,499 nests counted in March 2000 (Table 1), but this difference might be partly due to our interpretation of where the boundary of "Main Colony" lay. In 2000 there was no clear boundary of the colonies; small clusters of nests were scattered along most of the southern Malabar shore. The biggest difference between the two counts was in the west of Malabar, including the Gionnet and Frigate frigatebird colonies. We found 1,774 nests here whereas Diamond (1974), who explored the area thoroughly (pers. comm.), reported only 249 nests with sitting adults in 1967-1968. Red-footed Boobies have greatly expanded their colonies in this part of Malabar Island, probably as a result of the cessation of human exploitation and disturbance which was common there until 1967 (Diamond 1975, Reville 1980).

The counts of fledglings appeared to be higher in 1967-1968 than in 2000 (Table 1). This comparison is not meaningful, however, because breeding success might have differed among the years; Diamond (1974) sometimes pooled data from fledglings and older, second-year immatures; and at the time of our March 2000 census some fledglings had already left the colonies to roost elsewhere and were not counted.

We found no evidence of boobies nesting on Polymnie Island, Île Moustique, Île Esprit, Île Michelle, Passe Dubois, along the southern lagoon shores of Grand Terre from Passe Dubois to Bras Takamaka, or on any islets in these areas (Figure 1). The small colony of 13 nests at Gros Îlot Cavalier on the shore of Grand Terre in 1967-1968 (Table 1) was not occupied in 2000.

Frigatebirds

Frigatebirds were found in only three colonies on the lagoon shores of Malabar Island: Gionnet (which included Gros Îlot Gionnet), Frigate, and Middle Camp (Figure 1). These were the only colonies active during Reville's (1980, 1983) extensive research in 1976-1977. At that time all three colonies contained both species, but the bulk of the Great Frigatebirds nested at Middle Camp and the Lessers at Frigate (Table 2). We had insufficient time in 2000 to identify or count all the adult birds to confirm these distributions, except to note that the proportions of each species in the three colonies seemed similar to those in 1976-1977. In the 1960s frigatebirds also nested in Bras Takamaka in the southeast corner of the lagoon (Diamond 1971, 1975), but this area

was not used in the 1970s (Reville 1980, 1983) or since then (MB, pers. obs.).

In the 1960s the frigatebirds on Malabar Island, particularly in the Frigate colony, were frequently disturbed and preyed upon by people, and Reville (1983) suggested that the low numbers in that colony, greater use of the Middle Camp colony and nesting in Bras Takamaka were all consequences of this disturbance. Since 1967 the colonies have been protected and human disturbance generally limited to occasional visits by tourists in boats, restricted to the Gionnet colony and supervised by the Aldabra staff. The Frigate colony expanded, apparently due to immigration of Lesser Frigatebirds from Middle Camp and Bras Takamaka, and the latter colony ceased to be used (Reville 1983).

We counted 3,100 active frigatebird nests, nearly all containing large chicks (Table 2). It is difficult to make comparisons with previous counts in 1967 (Diamond 1975) and 1976-1977 (Reville 1983) because the counts were made at different times of year, and both of these authors used various factors to convert counts of adults or nests into the estimated total breeding population. We have used the least modified data, where possible, to compare with our counts (Table 2).

Diamond (1975) did not count all the nests in the large Middle Camp colony, but sampled sections of mangroves and extrapolated the results to estimate the total colony. He provided no direct estimates of active nests, but stated that the count of adult females in trees corresponded closely with the number of nests, and this count is summarised in Table 2. Using various conversion factors, Diamond (1975) estimated the maximum nest count at 1820 Great and 5352 Lesser Frigatebirds, and we applied his conversion factors to estimate the numbers in the four colonies used at that time (Table 2).

Reville (1980, 1983) did not use sampling or adult:nest ratios, but counted directly all the nests in each colony from a boat when there was maximum occupancy between August and November. He found little difference between 1976 and 1977 in the numbers and distribution of the two species in the three colonies (Table 2). The totals given in Reville (1983) are slightly higher than those given in his thesis (Reville 1980), and we assumed that the former are the revised, accurate counts. He found no significant difference between years in the breeding success of monitored sub-colonies of either species (Reville 1980). Consequently, we applied his fledgling:peak-nest-count ratio (0.67 for Great and 0.25 for Lesser; Reville 1983) to estimate the average number of fledglings in 1976 and 1977 (Table 2). This provides a crude estimate of the number of occupied nests expected late in the season, to compare with our March 2000 data. Our count was 29% higher than this estimate of fledglings for both species. The greatest numerical difference was in the Frigate colony.

Reville (1983) concluded that there had been little change in the numbers of frigatebirds between 1967 and 1976-1977, and that the differences between his and Diamond's (1975) estimates were due to differences in methods of counting nests and in estimating maximum nest counts. The distribution and relative proportions of the two species had, however, changed, and were explained by the cessation of human persecution, especially at the Frigate colony (Reville 1983). The relatively

TABLE 2

Counts of frigatebirds at the Aldabra colonies in 1967 (Diamond 1975), 1976-1977 (Reville 1983) and March 2000 (this study). See the text for methods used to adjust previous counts to allow comparison with the March 2000 count.

		Colony				
Date and measure	Gionnet	Frigate	Middle Camp	Bras Takamaka	Total	
Oct-Nov 1967: estimated nests from female count						
Great Frigatebird	46	42	583	60	731	
Lesser Frigatebird	0	0	1,428	257	1,685	
Both species	46	42	2,010	317	2,415	
% per colony	1.9	1.7	83.2	13.1	100	
Aug 1967: estimated maximum nest count						
Great Frigatebird	160	87	1,554	19	1,820	
Lesser Frigatebird	0	0	4,660	692	5,352	
Both species	160	87	6,214	711	7,172	
% per colony	2.2	1.2	86.6	9.9	100	
Aug-Nov 1976 and 1977: maximum nest count						
1976	Great Frigatebird	234	976	1,508	0	2,718
	Lesser Frigatebird	131	2,817	93	0	3,041
	Both species	365	3,793	1,601	0	5,759
1977	Great Frigatebird	192	545	1,511	0	2,248
	Lesser Frigatebird	116	2,369	355	0	2,840
	Both species	308	2,914	1,866	0	5,088
Mean 1976-1977						
Great Frigatebird	213	761	1,510	0	2,483	
Lesser Frigatebird	124	2,593	224	0	2,941	
Both species	337	3,354	1,734	0	5,424	
% per colony	6.2	61.8	32.0	0.0	100	
1976-1977: estimated number of fledglings						
Mean 1976-1977	Great Frigatebird*	143	510	1,011	0	1,664
	Lesser Frigatebird**	31	648	56	0	735
	Both species	174	1,158	1,067	0	2,399
	% per colony	7.2	48.3	44.5	0.0	100
March 2000: count of active nests						
Both species	283	1,668	1,149	0	3,100	
% per colony	9.1	53.8	37.1	0.0	100	

*Estimated number of fledglings assuming 67% breeding success in Great Frigatebirds (Reville 1983)

**Estimated number of fledglings assuming 25% breeding success in Lesser Frigatebirds (Reville 1983)

small differences between 1976-1977 and 2000 could be explained by variations in the proportion of adults breeding (see Reville 1980, 1983), or differences in breeding success prior to the fledgling census.

Our conservative conclusion is that the numbers and distribution of frigatebirds in 2000 were similar to, or slightly higher than those in 1976-1977. Obviously, a more detailed investigation is needed to show if these populations are indeed stable. This

should include identification of the species in each colony and ideally cover several years to account for variations in breeding success. The work of Diamond (1975) and Reville (1980, 1983) provides a valuable baseline for such comparisons.

Changes in booby and frigatebird populations

The available data do not permit firm conclusions about changes in the Aldabra populations of boobies and frigatebirds. The few counts used differing methods and sampled at different times in the breeding seasons. There are insufficient data to account for variations in the proportions of adults breeding and in breeding success. The number of pairs and the spatial distribution of Red-footed Boobies nesting during the NW monsoon season have both increased since 1967-1968. The area with the most complete coverage, Malabar Island, showed a 51% increase in adults incubating during the NW monsoon season (Table 1). Part, or maybe all, of this increase can be attributed to the cessation of predation and reduction of disturbance by people after 1967. Although Feare (1978) thought that humans were unlikely to have affected boobies on Aldabra, it is difficult to imagine that the boobies were spared the predation and disturbance from fishermen who were killing frigatebirds for food on Aldabra, especially on western Malabar (Diamond 1975, 1979, Stoddart 1984). Most of the colonies of Red-footed Boobies in the Indian Ocean have disappeared as a result of human disturbance, introduced predators, habitat change and direct predation (Feare 1978, Carboneras 1992).

As discussed above, there were dramatic changes in the distribution and relative proportions of the frigatebird colonies between 1967 and 1976, but Reville (1983) concluded that the total breeding population had changed little during that interval. The differences between the 1976-1977 and 2000 censuses appear relatively minor and might be explained by variations in the proportions of adults breeding or in breeding success. It is surprising that the numbers of breeding frigatebirds have not increased noticeably since the period of exploitation and disturbance by humans in the 1960s.

Recommendations for future monitoring

Direct counts of both booby and frigatebird nests from a small boat provide an efficient censusing method. The complex sampling techniques used for both groups by Diamond (1974, 1975) are not necessary. Reville (1980, 1983) reached the same conclusion, and used direct counts of all nests to census frigatebirds. Estimates of the total breeding populations require extrapolations from nest counts to account for nests missed, asynchronous laying and laying of replacement clutches. Long-term monitoring, however, is best done using the actual nest counts, with minimal extrapolation or correction of data. With suitable planning, logistical support and tidal cycles, most of the booby and all the frigatebird nests in Aldabra Atoll can be simultaneously counted from a small boat in 10-14 days. Estimating year-round populations of boobies will require several counts to cover the different phases of

breeding.

Aerial photography of colonies has been used to census seabird colonies, with mixed success (Harris & Lloyd 1977, Buckley & Buckley 2000). This method might be suitable for frigatebirds and boobies on Aldabra, when aircraft are available at the landing strip on nearby Assumption Island. Simultaneous boat sampling will be needed to ground-truth aerial photographs and identify the ratios of breeding and non-breeding birds appearing in the photographs.

Monitoring of Red-footed Boobies

Laying appears to occur in at least two fairly synchronised pulses through the year on Aldabra. Some pairs have eggs while others have large chicks or dependent fledglings. Ideally one should count the numbers of nests during incubation in each breeding pulse. Monitoring of laying chronology will be needed to plan these censuses for the optimal date. At least one complete census can be done at the same time as the complete count of frigatebirds in mid-February through March (see below). Counts twice a year will also allow an index of breeding success to be calculated (ratio of large chicks or fledglings to the earlier count of nests with eggs).

Counting roosting adults in proximity to the nests should be considered, but is not essential unless Diamond's (1974) method of using nest:adult ratio is applied to estimate nests obscured by the tree canopy. When reporting census data a clear distinction should be made between direct counts and estimates made using this method.

Monitoring of frigatebirds

The most complete counts should be done at the peak of incubation, after laying is completed but before many nests have failed. For frigatebirds this raises the problem of disturbance, because during early incubation nests which are vacated are generally plundered by males seeking nesting material (Reville 1980). Clearly any census undertaken during this time should be limited to parts of the colony which can be counted from a boat 30 m or more from the nests to minimise disturbance and nest desertion. Counts made during the late chick-rearing stage, such as our count in March, are far less likely to cause nest failure because there are very few adults seeking nesting material at this time, and even if adults are flushed, the counts focus on the large chicks remaining in the nests.

As a compromise we suggest the following protocol for monitoring both populations and breeding success of frigatebirds at Aldabra. The method can be adapted for use in other areas. First, make annual counts of nests during early incubation in sections (sub-colonies) of each of the three colonies. These sections should be selected to allow counting from a boat at least 30 m offshore to avoid disturbing the birds. Identify the species of adult in each nest during these incubation counts to monitor changes in the relative proportions in each colony. Second, repeat these counts of selected sub-colonies at intervals through the breeding season, or at least during the late chick-rearing phase, to provide an estimate of breeding success.

Third, make a complete annual count of large chicks in all three colonies during late chick-rearing (mid-February through March). This count can be converted to a total nesting population by applying the nest success in the selected sub-colonies, or can be compared with similar counts in other years without any conversions. Identify all adults present during the late chick-rearing census to confirm the distribution of species in the colonies. Monitoring the effects of tourists at the Gionnet colony should continue.

Monitoring of the breeding chronology will be necessary to plan the timing of the census. Most laying in Great Frigatebirds occurs between mid-August and mid-November, but laying in Lesser Frigatebirds is more variable and prolonged, with most eggs laid between June and November (Reville 1983). Other seabirds, such as White Terns *Gygis alba* nesting in the mangroves, can be counted at the same time as the counts of boobies and frigatebirds, although additional effort will be needed to include tern nests not near these colonies.

Using kayaks for censusing

An ocean kayak proved to be an ideal platform for censusing frigatebirds and boobies nesting in mangrove trees. The shallow inlets and narrows around the colonies were easily negotiated with the kayak, which had a draught of 10-20 cm, and it could be towed or carried across shallower banks. The kayak could be used over a much wider tidal range than a larger boat with a deeper draught or motor, thus providing longer access to colonies. At low tides no boats could be used in Aldabra Atoll. The kayak could manoeuvre through the narrow channels around the colonies faster than a powered boat, reducing the time needed for censusing. A motor boat was used to carry the kayak to distant sites and provide a safety back-up. Finally, the kayak was virtually silent, greatly reducing the level of disturbance compared with a motor boat. Reville (1980) found that the noise of the motor was a significant cause of disturbance, and rowed or punted a dinghy around the frigatebird colonies to reduce disturbance.

Wind and rough water can limit travel by kayak, even in the lagoon. Most of our censusing was done along sheltered shores but required travel across exposed or open water. An ocean kayak, with a covered deck and sealed spray-skirt, permitted travel in choppy water where an open canoe or small rowing boat would be risky. Kayaking experience, a two-way radio, and supporting motor boat are essential safety requirements for this work.

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